(1)

REPORT OF SURVEY CONDUCTED AT

GENERAL DYNAMICS

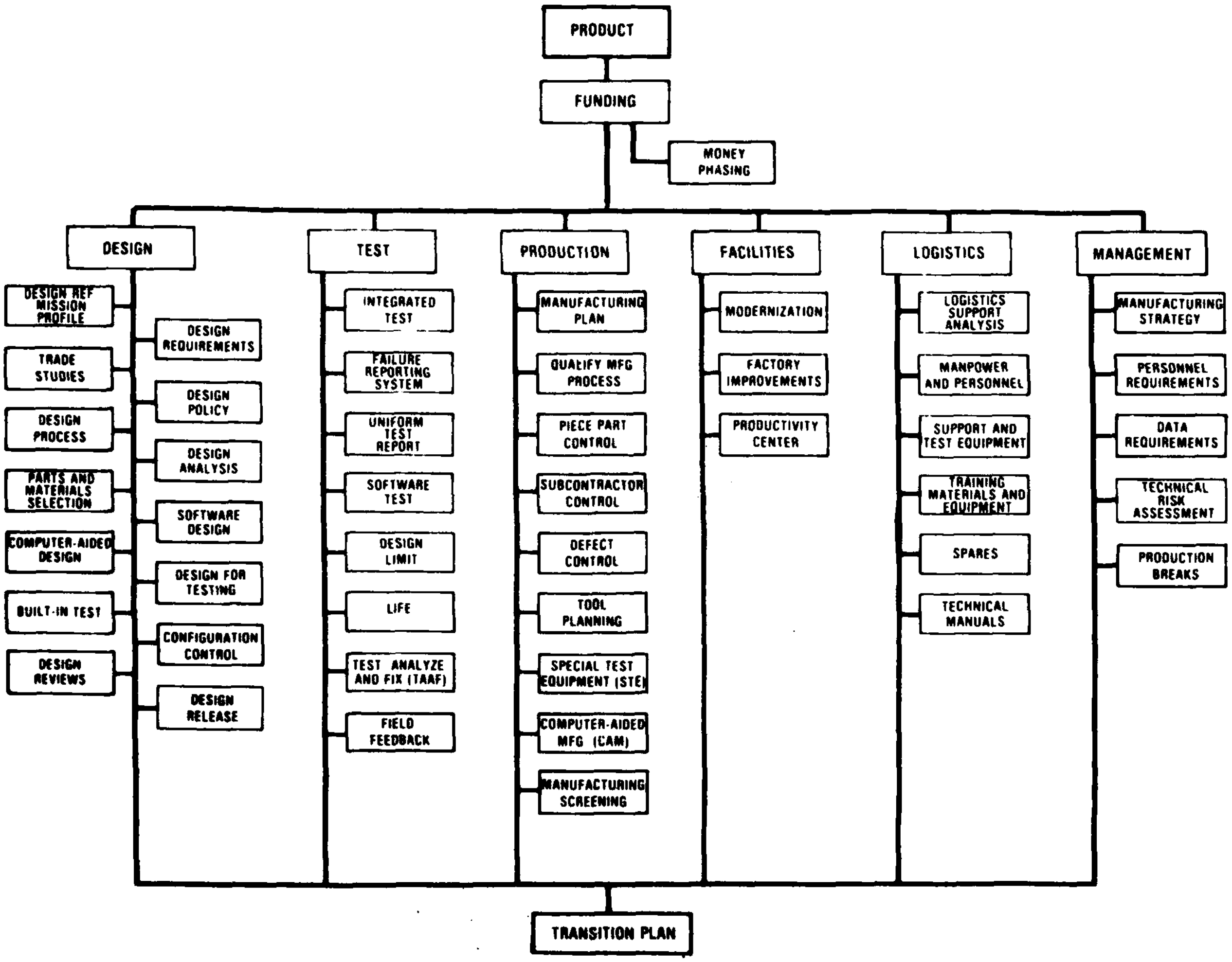
FORT WORTH DIVISION

FORT WORTH, TEXAS

MAY 1988

DoD 4245.7–M, "TRANSITION FROM DEVELOPMENT TO PRODUCTION"

CRITICAL PATH TEMPLATES



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The purpose of the Best Manufacturing Practices (BMP) survey conducted at this facility was to identify their best practices, review manufacturing problems, and document the results. The intent is to extend the use of progressive management techniques as well as high technology equipment and processes throughout the U.S. industrial base. The actual exchange of detailed data will be between contractors at their discretion. A company point of contact is listed in the report

The intent of the BMP program is to use this documentation as the initial step in a voluntary technology sharing process among the industry.

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SECTION 1

EXECUTIVE SUMMARY

The Best Manufacturing Practices (BMP) team conducted a survey of the General Dynamics Fort Worth Division (GDFW). The purpose of the survey was to review and document the best practices and potential industry-wide problems at GDFW. The intent of the BMP program is to use this documentation as the initial step in a voluntary technology sharing process among industry. The primary product at this facility is the F-16 aircraft.

1.1 KEY FINDINGS

There were many best practices observed at GDFW and detailed in this report. Some of the more significant findings included in this report are summarized below:

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"EXCELLENCE FOR USE" TEMPLATES: Organizes quality and maintenance data for ready use by design engineers.	7
AIRCRAFT STRUCTURAL INTEGRITY PROGRAM: A well developed, comprehensive program for improving and managing structural integrity.	7
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SECTION 2

INTRODUCTION

2.1 SCOPE

The purpose of the Best Manufacturing Practices (BMP) review conducted at General Dynamics, Fort Worth Division (GDFW) was to identify best practices, review manufacturing problems, and document the results. The intent of these reviews is to extend the use of progressive management techniques as well as high technology equipment and processes throughout industry. The ultimate goal of the BMP program is to reduce the life cycle cost of defense systems and strengthen the U.S. industrial base by using these techniques and technologies to solve manufacturing problems and improve quality and reliability.

To accomplish this goal, a team of Navy engineers supported by representatives of the U.S. Army, NASA, and the Department of Commerce accepted an invitation from GDFW in Fort Worth, Texas to review and document the most advanced manufacturing processes and techniques used in that facility. The review was conducted on 16-20 May 1988 by the team identified in Appendix C of this report. GDFW is engaged primarily in the production of the F-16 "Fighting Falcon," development of increased capability versions of the F-16 as well as the design and development of future generation aircraft. This was the first BMP review conducted at a major aircraft producer.

The results of BMP reviews are being entered into a database to track the best practices available in industry as well as common manufacturing problems identified by industry. The information gathered is available for dissemination through an easily accessible central computer. The actual exchange of detailed technical data will take place between contractors at their discretion on a strictly voluntary basis.

The results of this review should not be used to rate GDFW among other defense contractors. A contractor's willingness to participate in the BMP program and the results of a survey have no bearing on one contractor's performance over another's. The documentation in this report and other BMP reports is not intended to be all inclusive of a contractor's best practices or problems. Only selected non-proprietary practices are reviewed and documented by the BMP survey team.

2.2 REVIEW PROCESS

This review was performed under the general survey guidelines established by the Department of the Navy. The review concentrated on the functional areas of design, test, production, facilities, management, and transition planning. The team evaluated GDFW's policies, practices, and strategies in these areas. Furthermore, individual practices reviewed were categorized as they relate to the critical path templates of the DOD 4245.7-M, "Transition From Development To Production." GDFW identified potential best practices and potential industry wide problems. These practices and problems and other areas of interest identified were discussed, reviewed, and documented for dissemination throughout the U.S. industrial base.

The format for this survey consisted of formal briefings and discussions on best practices and problems. Time was spent on the factory floor reviewing practices, processes, and equipment. In-depth discussions were conducted to better understand and document the practices and problems identified.

2.3 NAVY CENTERS OF EXCELLENCE

Demonstrated industry wide problems indentified during the Best Manufacturing Practices surveys can be referred to one of the Navy's Centers of Excellence. They are:

* Automated Manufacturing Research Facility (AMRF)
  Gaithersburg, MD

* Electronics Manufacturing Productivity Facility (EMPF)
  China Lake, CA

* Metalworking Technology, Inc. (MTI)
  Johnstown, PA

2.4 GENERAL DYNAMICS, FORT WORTH DIVISION OVERVIEW

GDFW occupies Air Force Plant No. 4. It comprises 602 acres adjacent to the Carswell Air Force Base in Fort Worth, Texas. Facilities include 128 buildings covering a total of 6.9 million square feet. The major structure is a one mile long manufacturing building, which houses a linear flow process line ranging from fabrication processes to final assembly and test. The principal product of this facility is the F-16 "Fighting Falcon." Over 2,000 planes have been produced with another 2,000 projected with current deliveries scheduled for 17 Air Forces.

A large USA supplier network supports this program. GDFW purchases from the following approximate number of US companies:

Avionics/Systems	120
Equipment Items	250
General Material	<u>5,630</u>
Total	6,000 Companies

There is also an extensive co-production program of 43 companies which provide 135 discrete item/company combinations. These items are supplied for USAF aircraft as well as those of other countries. There are production lines in Belgium, Netherlands, and Turkey. These aircraft are delivered as GDFW airplanes. Approximately one-half of the F-16 flyaway cost is for government-furnished equipment.

Many of the current manufacturing practices in place at GDFW have resulted from the Air Force F-16 Technology Modernization Program. This successful effort has helped GDFW to develop a philosophy and methodology for technology innovation and implementation.

2.5 ACKNOWLEDGEMENTS

Special thanks are due to all the people at GDFW whose participation made this survey possible. In particular, the BMP team acknowledges the special efforts of F. A. "Mike" Curtis, Jr., Phillip M. Bunting, and Harry Englert, Jr. A great deal of preparation on their part was reflected in the quality and breadth of the presentations.

2.6 GDFW POINT OF CONTACT

While the information included in this report is intended to be descriptive of the best processes and techniques observed at GDFW, it is not intended to be all inclusive. It is anticipated that the reader will need more detailed data for true technology transfer.

The reader is encouraged to contact GDFW directly for the purpose of sharing or transferring technology. Any exchange of technology resulting from such a contact is strictly voluntary and at the discretion of GDFW.

The GDFW point of contact for the Best Manufacturing Practices Program is:

Mr. Harry Englert, Jr.
General Dynamics
Fort Worth Division
P.O. Box 748
Fort Worth, TX 76101
(817) 777-8537

SECTION 3

BEST PRACTICES

The practices listed in this section are those identified by the team as being among the best in the industry or as being particularly effective in GDFW's efforts to reduce life cycle costs of their products.

3.1 DESIGN

INTRODUCTION

GDFW is engaged in several state-of-the-art design related technologies. Perhaps the most significant is the wide use of **computer-aided design** (CAD). The extensive use of **product definition data** as a standard data model is imperative towards achieving a comprehensive computer integrated manufacturing environment. Also significant is the ability to utilize **computerized modeling** to simulate manufacturing and maintenance operations.

There is a strong **bias to change** for product improvement within the organization. This is reflected in many engineering based programs, including **producibility** and other **trade studies**, **response to field/fleet problems**, and a **structural integrity** program that have yielded positive results.

EXCELLENCE FOR USE TEMPLATES

GDFW has developed a series of "Excellence for Use" templates for organizing quality characteristics for ready use by engineers and designers. The templates are similar in format to the Navy's Best Practices Manual. Over 100 templates have been developed to date, drawing on information from Air Force and GDFW experience.

The "Excellence for Use" templates compress a large body of maintenance knowledge, developed since the 1950s, into a format that is easy for engineers and designers to use in avoiding what have proven to be design and manufacturing traps.

AIRCRAFT STRUCTURAL INTEGRITY PROGRAM (ASIP)

GDFW has a well developed F-16 ASIP program, which is composed of two major efforts: full scale development and fleet management. The ongoing ASIP assures structural integrity in the design, contributes to operational readiness through scheduled maintenance, and provides the basis for improved design criteria and methods for future aircraft.

Full Scale Development

Full scale development covers design criteria, analysis, ground tests, and flight tests to assure structural integrity in terms of strength, service life, and flutter characteristics.

Adaptive Flutter Suppression

One F-16 ASIP requirement is to design the aircraft such that the velocity of flutter (V_f) is 20% higher than the velocity limit (V_l). This is a complicated design problem because of the variety of external stores on an aircraft and the sequence in which they may be released. During the design stage, conventional solutions examine stiffness, mass, and pylon location. In the operational stage, mass balance, release sequence, and speed restrictions are examined.

New methods in flutter suppression technologies are being developed by GDFW for potential newly designed aircraft or for incorporation in existing aircraft to expand their stores carriage capabilities. One is the use of active controls for flutter. This concept uses sensors to identify flutter motion and to provide analysis of signals and feedback to control surface actuators in order to suppress flutter. The benefits of in-flight correction are: requires no knowledge of stores configuration; no restrictions on release sequence; adapts to changing flight conditions; data is available in real time; and accommodates symmetric and anti-symmetric flutter in clear air or turbulence. These new methods will enable the designer to meet ASIP flutter requirements for a wider range of stores carriage needs than can be achieved with current technology.

Service Life Analysis

The Fatigue and Fracture Group has developed the capability through independent research and development to analytically predict structural tolerance to flaws. A finite element based program known as AUTOCRK runs on a Cray XMP-24 and is used to calculate the stress intensity factor (ΔK) for the desired load/geometry condition with a flaw or crack as introduced by the user. Stress intensity factors generated by AUTOCRK are then entered into a family of programs known as ADAMSYS, which execute sequentially. ADAMSYS runs on a CDC Cyber 855 and has as output, through post processing, plots and graphs describing crack length relative to time. This information is then used to project scheduled maintenance intervals and to predict residual life. Utilizing this technology, GDFW has performed over 5,000 analyses since 1986.

Advanced Airplane Loads Procedures

GDFW has developed and uses a general static loads analysis procedure with an efficient interface to a finite element stress analysis model. It is being implemented with a versatile interface to aerodynamic data such as wind tunnel pressure data or theoretical aerodynamics data including computation fluid dynamics (CFD) methods. It operates through iterative aeroelastic solutions with six full degrees of freedom and can include vectored thrust engine mount load analysis and skin friction drag analysis.

Finite Element Analysis

The current structural finite element analysis effort utilizes a Cyber 855 scientific computer and a Cray XMP-28 supercomputer. Types of analyses performed are linear, material nonlinear, geometric nonlinear, large displacements to failure, elastic buckling eigenvalue, and thermal analysis. Finite elements are analyzed using a master model and satellite models in areas of high stress/strain gradients. Model generation is done with CADMESH (IBM), PATRAN (IRIS), GD GIFTS (VAX), NASTRAN (CRAY), ABAQUS (CRAY), and EDITORS (VAX, CYBER, and IRIS). These analyses have the capability to access part data in CADAM for initial structure geometry data.

Fleet Management

Along with full scale development, fleet management is a major component of the ASIP. Fleet usage is monitored because actual usage may differ from design requirements. The variation in usage among airplanes and countries affects maintenance requirements, and properly scheduled maintenance can reduce maintenance costs. Readiness and safety are enhanced by advance scheduling of structural maintenance actions. GDFW is actively supporting its customers in monitoring the operational use of the F-16's. Flight data is recorded on operational aircraft and evaluated to adjust maintenance schedules as required to reflect fleet average and individual aircraft usage.

STATISTICAL TECHNIQUES

GDFW has applied statistical processes to analyze similar composite materials provided by several suppliers, identified fundamental differences among the suppliers' processes, and in a few cases, predicted when supplied products would fail under test. In one case, differences between materials from two suppliers, both of which met a common specification, led to the discovery that one supplier's process was out of control. These efforts have been accepted by the suppliers, who are undertaking process improvements.

The concept of statistical process control (SPC) is being extended to the point of determining the characteristics of composite materials as functions of the processes that produce them. Eventually, this data is expected to guide designers on the use of these materials. Additionally, pilot SPC projects are in place for both production and administrative processes.

SEALING OF INTEGRAL FUEL TANKS

Conventional integral fuel tank sealing had previously been accomplished by the multiple barrier method. This method employed room temperature curing of faying surface sealant. However, in the early 1950's, the General Dynamics Convair Division developed the heat curing (thermoset) nitrile-phenolic adhesive sealant AF-10, which was later characterized in the late 1970's by exceptionally low maintenance costs relative to conventional sealants.

Based on the attractiveness of the low maintenance costs, GDFW undertook Independent R&D and Contract R&D to fully characterize AF-10 against new materials, conduct element tests, demonstrate manufacturing capability, and perform cost analyses. These efforts were completed in 1982 resulting in delivery of an F-16 with center and aft fuselage integral fuel tanks sealed with AF-10. Trade-off studies, testing, and service experience demonstrated the positive attributes of adhesively sealing integral fuel tanks. An ECP for new production followed, authorizing AF-10 adhesive sealing for these tanks on all follow-on F-16 aircraft. Major attributes over conventional integral fuel tank sealant methods are lower manufacturing costs, less weight, and more reliable fuel tightness in service.

EVALUATION OF COMPETING STABILIZER DESIGNS

During the initial F-16 flight testing, GDFW in conjunction with the Air Force determined that a larger horizontal stabilizer would result in improved take-off and landing performance as well as improved pitch control at low air speed/high angle of attack.

In order to select an optimum design, weight and cost criteria were initially defined for candidate concepts identified in Independent R&D activities. As the evaluation proceeded, GDFW expanded its areas of consideration beyond weight and cost to include producibility, repairability, labor skills required, and long term structural integrity in terms of corrosion resistance.

By employing a team engineering and life cycle engineering approach to trading off each of these characteristics, GDFW was able to successfully meet its weight and cost goals and ultimately produce a corrugated design of significantly lower risk of corrosion than that associated with the competing honeycomb design. One piece pre-cured graphite-epoxy skins are rivetted to a one piece drop-hammer-formed aluminum corrugation.

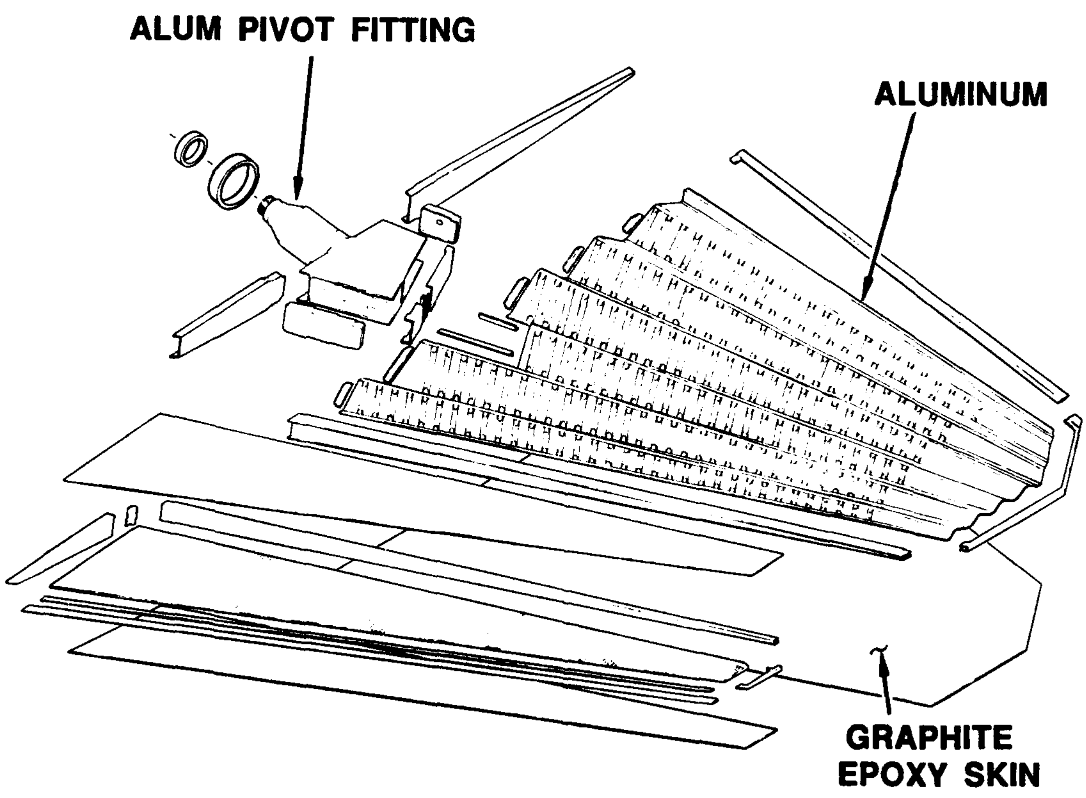

FIGURE 3-1: MODIFIED HORIZONTAL STABILIZER DESIGN REDUCES COST AND CORROSION SUSCEPTIBILITY

INJECTION MOLDED THERMOPLASTICS

GDFW, in conjunction with the Air Force Productivity, Reliability, Availability, Maintainability (PRAM) Program Office, is evaluating plastics and composites as a replacement for metal components.

Projected life cycle savings for 250 currently identified parts are $60 million for acquisition and $63 million for fuel costs. GDFW's goals are cost, volume, weight, and environmental impact reduction, while improving reliability and maintainability. This has extended beyond GDFW equipment to include recommendations on GFE and subcontractor provided equipment. An aggressive, continuing effort is planned to apply plastic moldings to subsystem components on future F-16 versions.

To facilitate this effort, GDFW has procured an Engle's CC90 injection molding machine for manufacturing components in-house and is developing automated techniques to support it.

NC capability for mold design and manufacturing is being developed. Moldflow software is being used to select mold injection temperature, cooling temperature, and other parameters for over 100 materials in the Moldflow database. Users have indicated that Moldflow paid for itself by the second mold. GDFW intends to be able to go from art to part in six weeks by the end of the year.

Injection molded circuit boards are another application being investigated by GDFW.

ELECTRICAL HARNESS DATA SYSTEM

The Electrical Harness Data System is a CAD/CAM system designed to develop and transmit computerized data to a variety of electrical harness assembly stations.

Once the engineer has designed the required wire harness on a CAD workstation, the data is electronically transferred to various manufacturing systems groups which accomplish make or buy decisions, develop bills of materials and develop subassembly requirements. In addition, they can generate harness board placards, test codes to verify the assembly of the harness, wire number and reference designator labels, harness assembly kit requirements, and connector requirements for pin insertion robots.

The benefits of this system include manufacturing access to engineering data in a more timely manner, increased accuracy of wiring harness design, and a reduction in engineering change notices.

COMPUTER MOCK-UP (COMOK)

GDFW has the solid modeling capability to develop systems to verify assembly and tool clearances for manufacturing and repair. Solid model data eliminates the need to experiment with expensive physical mock-ups of prototype systems. CATIA software is used on an IBM 3090 System to design aircraft assemblies. Animation is then used to verify clearances of components which will be inserted into close spaces.

Operational benefits are system integration and coordination, common model database, and design coordination. In-process and interdisciplinary status is always available for management inspection.

This technology is supportive to a project called "Crew Chief," which will use COMOK techniques to build a library of standard Air Force maintenance hand tools. Use of COMOK will ensure proper clearances when these tools are used in the field.

COMOK will result in more rapid development of aircraft designs because of time and cost saved creating physical mock-ups. Other benefits are early verification of tool clearances, fewer design modifications, and coupling and harness interface verification. There are no definite plans for COMOK on F-16 programs. However, these methods are being applied on other current projects.

CAD/CAM ENGINEERING

GDFW has committed to instituting a comprehensive CAD/CAM engineering effort featuring CADAM and CATIA to drive its computer integrated manufacturing (CIM) operations. CADAM and CATIA are used in concert via the GDFW CAD/CAM hardware/software integration effort. CADAM is the basic software system for mechanical design of product, tooling, and NC programming. CATIA is the basic software for use in defining surfaces and solid models used to produce master surface definitions, master dimension data bases, complex surface NC cutter location files, QA verification data, and COMOK. These systems are currently employed for all new designs for the F-16 and all new programs at GDFW.

The GDFW CAD/CAM data set is the replacement for the previously used conventional drawings and contains complete digital product definition for use as input to CAM processes.

DRAWING AND SOLID MODELING DATA

GDFW is using CAD systems extensively to create drawing and part data. The data is managed on an IBM 3090 system.

CADAM 20.1.1 is being used to create parts. The data, organized in a format consistent with MIL-STD-100, is being used for mechanical and electrical design and to produce tool designs, numerical control code, wire routing, and drawings.

More sophisticated applications utilize CATIA V2R2PTF2 to provide solid model data for master surface data, master dimension data, complex surface NC code, QA verification, and computerized mock-up. Implementation philosophy focuses on features, application opportunities, use of current data, and pursuit of neutral data.

The total physical plant has also been put onto the CAD system for planning purposes. This capability gives GDFW the opportunity to modify floor layouts and plan new equipment installations efficiently without disrupting the shop floor.

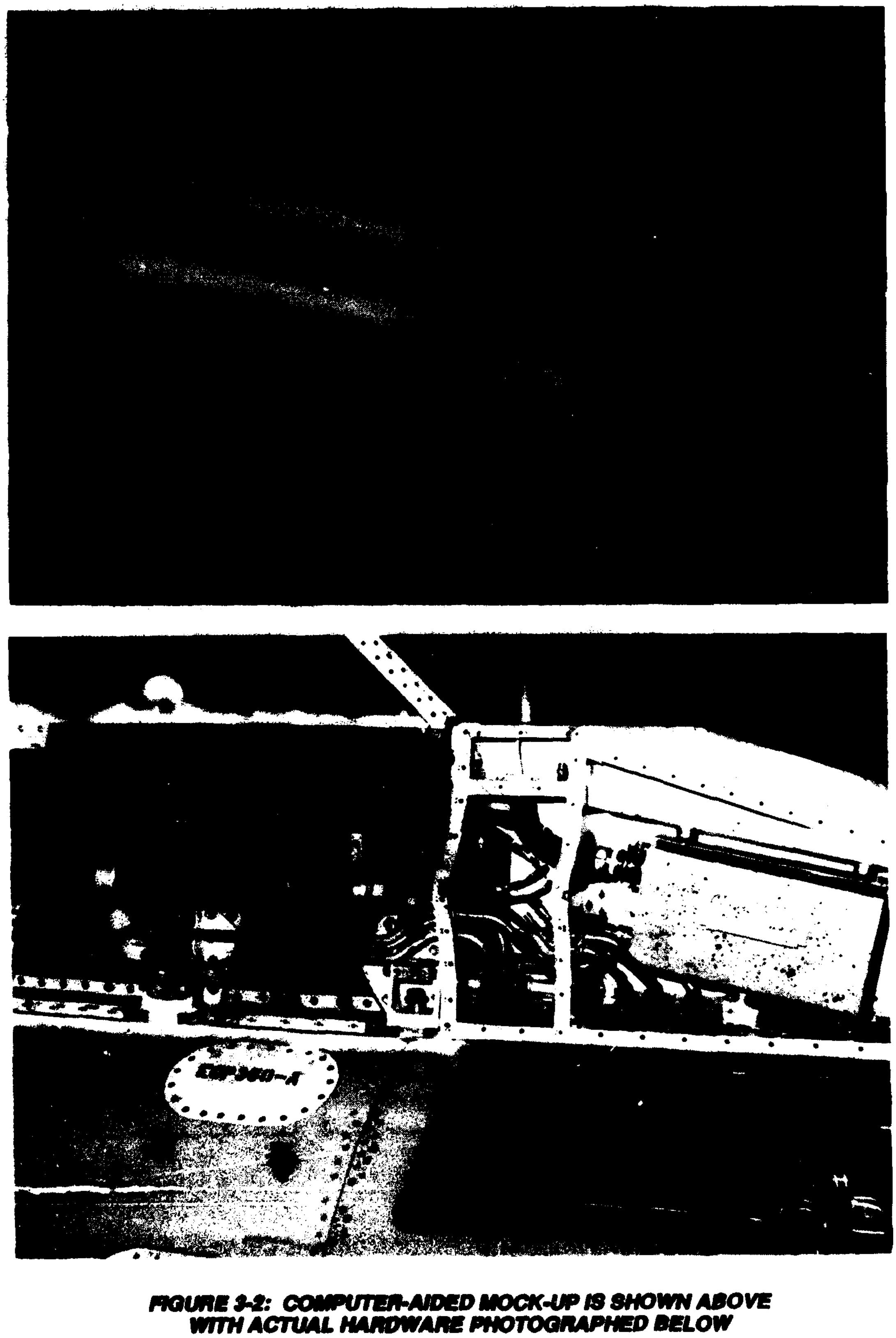

FIGURE 3-2: COMPUTER-AIDED MOCK-UP IS SHOWN ABOVE WITH ACTUAL HARDWARE PHOTOGRAPHED BELOW

PRODUCT DEFINITION DATA (PDD)

GDFW uses modified Product Definition Data Interface (PDDI) techniques for driving computer integrated manufacturing (CIM) operations. These techniques preceded the Product Definition Exchange Specification (PDES).

PDD enables engineers to produce electronic readable data sets in lieu of drawings. This data will support the many manufacturing automation projects which are currently in place or are in the process of development. PDD provides for feature recognition and automated product data extraction.

The current PDD capability at GDFW includes the following:

* Aircraft Surface/Shape Data
* Machined Detail Parts
* Sheet Metal Detail Parts
* Composite Laminates
* Assemblies
* Flat Pattern
* Fluid Systems Tubing

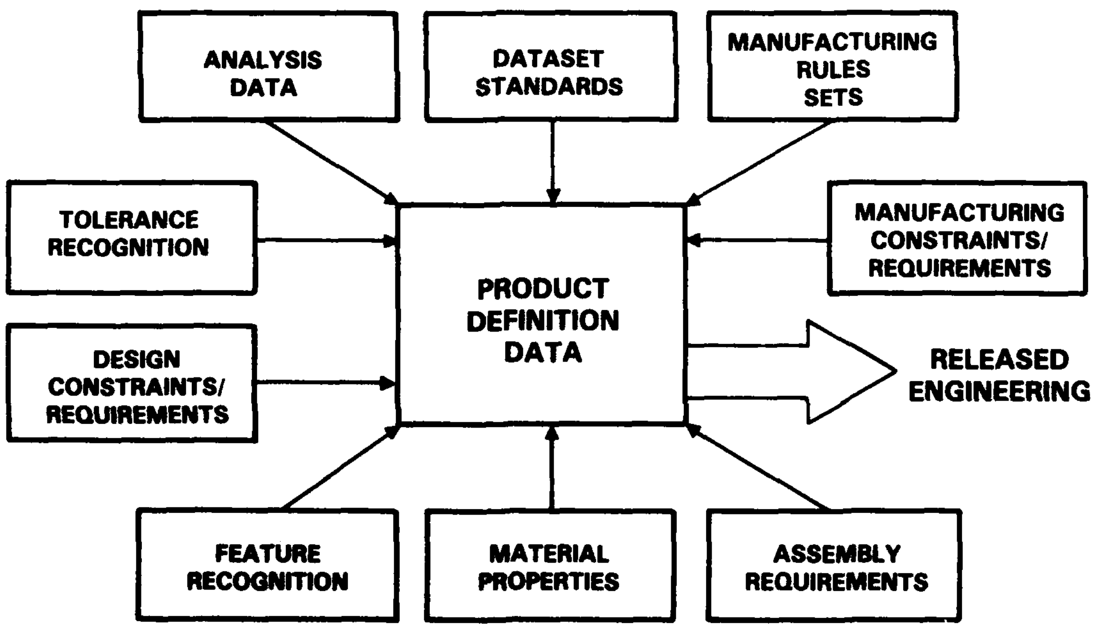

FIGURE 3-3: PRODUCT DEFINITION DATA IS CRITICAL TO INTEGRATING DESIGN AND MANUFACTURING

ENGINEERING CHANGE CONTROL ROOM

The engineering change process is particularly hard to manage in the aircraft industry. This is due to the large volume of changes, the number of functional organizations and people involved, the potential for unanticipated adverse effects, and the need to ensure proper application of changes to aircraft yet to be built, in production, and perhaps already in service. There were 7,968 engineering/contract changes on the F-16 in 1986 alone. While most of these occurred prior to production, a complex change can involve contract modifications, purchased materials, manufacturing processes, quality control, field test equipment, maintenance documentation, field modification kits, and customer billing.

GDFW has set aside a room solely for managing the engineering change process. About 24 feet square, the walls are covered with carpeting to which Velcro tape will adhere. On three of the walls are Velcro backed flow diagram symbols and completed copies of all forms used for (1) initiating a change, (2) developing a change proposal for submission to the customer, and (3) implementing an approved change. This includes Class II as well as Class I change processes. The room is used by those involved in coordinating engineering changes and for all regular change coordination meetings. The room is designed to teach people (GDFW, customer, supplier, co-producer, etc.) how the engineering change process must operate and help participants learn how to keep track of the status of each proposed or approved change action.

This room is a model for multi-discipline coordination and management processes that are increasingly common to complex manufacturing situations.

IMPLEMENTATION OF RETROFIT CHANGES

GDFW procedures ensure that all retrofit changes are made in accordance with an Engineering Release and that the changes work as intended. The five major steps in the process are:

1) The configuration requirements of each aircraft, the factory scheduling factors, and the data requirements are compiled concurrently.

2) GDFW personnel may install a prototype kit on an active aircraft to test the materials, installation procedures, data, process, and performance.

3) A second test kit (including all formal instruction and hardware required for the installation by the designated customer maintenance level) is developed and installed and tested by customer personnel. (Kitproofing)

4) The kits are assembled and shipped to the fleet or depot.

5) In some cases, an Air Force/GDFW program called "Lead-the-Fleet" follows actual performance of the kits on aircraft that have been identified as being most likely to subject the kits to the greatest and most demanding early use. The intent is to gain experience rapidly and mature the kits quickly in situations where any shortcomings are most likely to occur. For example, the mission of F-16's to climb to high altitudes for interceptions incurred environmental control system (ECS) shutdowns. A "Lead-the-Fleet" program was established in two air forces to modify a few aircraft to assure that the proposed change solves the problem without undesirable side effects.

3.2 TEST

MATURITY UPGRADE THROUGH TEST/FIELD FEEDBACK

Performance and maintenance data are collected worldwide and relayed back to the central product support activity.

This is accomplished in three ways. The first is by standard military data collection and reporting systems, dependent on the particular military customer. The second method, known as the Central Data System (CDS) augments the first by providing real time reporting of more detailed information, including maintenance narratives. The CDS is maintained by a third party under an Air Force contract. The third method utilizes field service reports generated by both contractor and customer. Data acquired through all three methods is transmitted to the GDFW Product Support Group, which in turn coordinates its review among the AFPRO and the GDFW engineering and quality organizations.

GDFW can respond to field generated technical feedback by recommending changes during full scale development and production. A significant number of changes directly affect design. By monitoring corrective actions taken as a result of field feedback on reliability and maintainability problems, GDFW has identified significant improvements in mean flying time between failures (MFTBF) and in discrepancy reports.

GDFW has found field feedback to be particularly useful in evaluating weapon system performance in the operational units of the Air Force. Here, aircraft have significantly larger exposure to elements that may affect maintenance or operational aspects than encountered in development and/or operational tests and evaluation programs. Typically, these are:

* Maintenance and operations totally by the Air Force with technical orders and support equipment supplied for the weapon system.
* Variations in aircraft. Small, but sometimes significant.
* Large variety of training and operational missions.
* Variations in air crews and maintenance skill levels.
* Variations, long and short term, of physical environment.

QUALITY ASSURANCE REPORTING SYSTEM

GDFW has developed a comprehensive on-line data system that records and provides information on the quality history of aircraft, either individually or by group. It also provides data about specific equipment, hardware, or raw materials. The system allows direct recording of nonconformances, dispositions, and corrective actions from the factory floor and a number of remote sites. Reports are produced in a variety of formats including on-line query and graphics.

The system has many uses, including ensuring that all known discrepancies are corrected before an aircraft is turned over to the customer. It is worthy of note because of its capabilities, user convenience, scope of coverage, and range of uses.

Together, this system and the Central Data System can provide a complete service and quality history for each Air Force F-16. The functional equipment tracking and reporting systems are known as the "Blue Book" and "Blue Streak" for the factory and field level performance tracking, respectively.

3.3 PRODUCTION

SUBCONTRACT MANAGEMENT

Subcontract management at GDFW is very effective. Policies require subcontract management to flow down requirements, to educate each subcontractor on the requirements of the subcontract as well as the key elements of the prime contract, and to communicate to the subcontractors what is required of them. Resident interface is established at critical vendors. Technical and production specialists with working experience in key or problem commodities are provided to assist subcontractors when required.

The Subcontract Management Group has been able to utilize multi-year contracting advantageously in order to provide maximum flexibility and significant economies.

GDFW has implemented a supplier rating system which measures, analyzes, and reports supplier performance against purchase order requirements. Identification of problem suppliers and implementation of corrective action is effective. It has substantially improved subcontractor responsiveness to contract requirements.

FACTORY LIAISON AND INSPECTION RESOURCES (FLAIR)

Some suppliers provide materials and components for a number of prime contractors, which in turn, serve a single customer. GDFW has begun a program of cooperation with other primes in using a single on-site representative to handle many routine interfaces with a common supplier. The program is in operation with four suppliers involved in three different product areas. The representatives are third party contractors that bill each cooperating prime on an actual time-spent basis. GDFW has promoted the FLAIR program within the Aerospace Industries Association and is building it into plans for future aircraft programs.

The FLAIR Program has the potential for simultaneously improving supplier relations and reducing costs. The technique can probably be developed to serve a variety of common supplier situations.

QUALITY CONTROL CORRECTIVE/PREVENTATIVE ACTION SYSTEM

GDFW has developed systems to ensure delivery of quality aircraft that comply with contract specifications or documentation of any non-compliance. The capstone of these systems is the corrective action system that is designed to prevent the recurrence of significant quality problems. Using the 80/20 principle, the system concentrates on the relatively few nonconformances that can lead to the bulk of cost or production problems.

The critical nonconformances are identified by use of standard criteria. They are then investigated to determine the cause, and corrective actions are taken. Corrective action specialists are co-located in the production environment and work with material, engineering, manufacturing, and tooling specialists to ensure that corrective actions are completed. These actions are reported to the customer.

This is a well designed and well implemented closed loop system that has resulted in nonconformance rates below industry norms.

3.4 FACILITIES

INTRODUCTION

A continuing commitment towards cost control and quality improvements is evident throughout the GDFW facility. The team was most impressed with the commitment to a **computer integrated manufacturing** environment. This commitment is evidenced by the **Advanced Machining System** and related technologies such as **Automated Numerical Control, the Shop Floor Control System**, and the extensive utilization of **robotics and non-contact measurement techniques**.

The F-16 assembly operation, as it now exists, represents a mature production operation. It has evolved from 1978 to the present time with a decrease in assembly hours from approximately 110,000 hours for the first production F-16A to approximately 37,000 hours for the last F-16A delivered to the USAF in 1985. The maturity is sometimes less than expected due to major block configuration changes about every two to three years.

ENVIRONMENTAL RESOURCES MANAGEMENT

General Dynamics has a corporate policy of protecting the environment and an ultimate goal of achieving zero discharge of hazardous wastes from all facilities.

GDFW has identified all hazardous waste streams leaving the plant. A plan has been developed to change waste generating processes and recycle, reduce the volume, or harmlessly burn nearly all hazardous materials. Since the plant is a government-owned facility, the Air Force has been willing to fund some of the R&D and recycling processes. Although in operation only about two years, this program is already reducing the amount of hazardous effluents even though aircraft production is increasing. While zero discharge will not be reached for five years, it will be approached through a series of processes that are cost effective in their own right. These changes are being made by many separate units operating under the guidance of a coordinating committee and a small staff.

This is a major corporate initiative resulting from a business decision intended to improve productivity and profitability and to reduce liability. GDFW states that it was not done in response to regulatory pressures.

CUTTING TOOL MAINTENANCE

GDFW has developed and implemented a work cell for restoring worn and damaged end mills back to their original geometries. The cell consists of a 5-axis CNC welder manufactured by Sciaky and a 5-axis CNC Huffman grinder.

End mills are purchased at .003 inch over nominal size. Once they become .007 inch below nominal size they are sent to the cell for weld build-up and grinding. No pregrinding or preheating is required prior to welding. End mills are plasma-arc welded on the cutting edge with an 8% cobalt material. These welded end mills are then ground back to nominal size and put back in service.

This process can be repeated about 16 times before the end mill has to be scrapped. Failure rate of the refurbished end mills is less than 2%. Cost of this process averages approximately $25 per end mill. Average cost of a new end mill is $75. This savings alone more than justifies the use of this practice. Cost of the cell was justified on the annual requirement of 10,000 end mills per year ranging in diameter from 1 inch to 2 inches.

AUTOMATED TUBE FABRICATION

GDFW is changing over from a manual method for tube fabrication to a more automated system. This change will integrate the existing technology such as CNC tube benders and a laser cutting machine for weld preparation. It will also integrate with a vision system for checking formed tubes to ensure that they meet plan requirements.

The vision system is built by EOIS, Santa Monica, CA. It utilizes three cameras, a calibrated grid table, and a computer system that checks the tube against the geometry data from design. The system, which is currently being brought on-line, checks the tube form and provides X, Y, Z feedback on a screen or on hard copy as required.

This system, when tied into the CAD/CAM database, will provide an on-line accurate means of checking fabricated tubes. It will minimize the need for standard shapes and the manual process of block set-ups to check the tube form.

THEODOLITES AND PHOTOGRAMMETRY APPLICATIONS

GDFW utilizes a theodolite measuring system to obtain horizontal and vertical angles and to generate numerical values for close range, non-contact measurements. This practice will aid in eliminating the need for hard master control media. Very accurate dimensions can be obtained by using targets in much the same manner as tooling balls are commonly used. These dimensions are used for evaluation of models in the CATIA system. A spin-off application is the checking of subcontractor and co-producer master tools ensuring compliance and correctness of delivered components.

An automated theodolite system is being developed as part of an Air Force Technology Modernization program. The project is called Contour Measurement of Large Shapes (CMOLS) and will be capable of gathering large amounts of measurement data in a short time span. The initial application of the CMOLS system will be to take measurements on NC fabricated tooling and compare those measurements back to the design model that was used to create the original NC program. A hard copy report and color graphics display of analysis results will be available to the operator in near real time.

The system will:

* Establish a communications network from the mainframe to the shop floor.
* Develop a drive library for coordinated motion of the measuring instruments and the target projector.
* Automate the measurement equipment and process.
* Perform shop floor analyses traceable to the mainframe design model.
* Provide results and simple visual aids to the operator.

Rapid data acquisition coupled with shop floor analysis could enable GDFW to produce production ready contoured tooling without the use of master forms.

Photogrammetry is a new process also used at GDFW to measure tooling. This system requires more time than the theodolite method because of film development and reading times. GDFW indicated that early results are promising with excellent data accuracy being an expected product.

MATERIAL HANDLING (ICMMA/ATSARS)

The Inventory Control and Material Management in Assembly (ICMMA) project established and demonstrated an integrated system for the storage, retrieval and delivery of assemblies to several workstations, including inspection. It also provided a better method of tracking, controlling, and delivering plant-wide purchased line stock (fasteners and miscellaneous hardware).

The ICMMA system consists of six major computer based subsystems; an automated storage and retrieval system (AS/RS), an automated guided vehicle (AGV), conveyors, the corporate IBM mainframe, a micro vax cell controller, and hand held inventory data collection devices.

The Automated Tool Storage and Retrieval System (ATSARS) is an existing system for storage and retrieval of production tools. The ATSARS consists of two aisles of unit load racks, fork trucks, automated tool sizer, in-line scale, bar code readers, and an on-line tool tracking system. The system will be integrated with other factory systems to permit tool requests from individual stock rooms and task centers throughout fabrication and production. All production/fabrication tools assigned to the ATSARS are tracked and accounted for whether stored in the AS/RS, the tool manufacturing area, or used on the factory floor.

ADVANCED MACHINING SYSTEM

The Advanced Machining System (AMS) program is a major effort nearing completion at GDFW. This program is jointly funded by the U.S. Air Force and GDFW.

The system will be capable of unmanned operation and will encompass design, engineering, fabrication, and product verification in a paperless environment. The major components of this program are an integrated manufacturing system, a flexible machining system, and robotic systems for various functions.

The system will include:

Six five-axis CNC machining centers
Two automated material handling systems
Two coordinate measurement machines
Automated storage and retrieval system
Robot load/unload and tab removal stations
Chip handling and coolant delivery systems
FMS controller
Product definition data
Integrated standardized planning
Automated numerical control
Shop floor control system
Integrated manufacturing database system
Quality control system

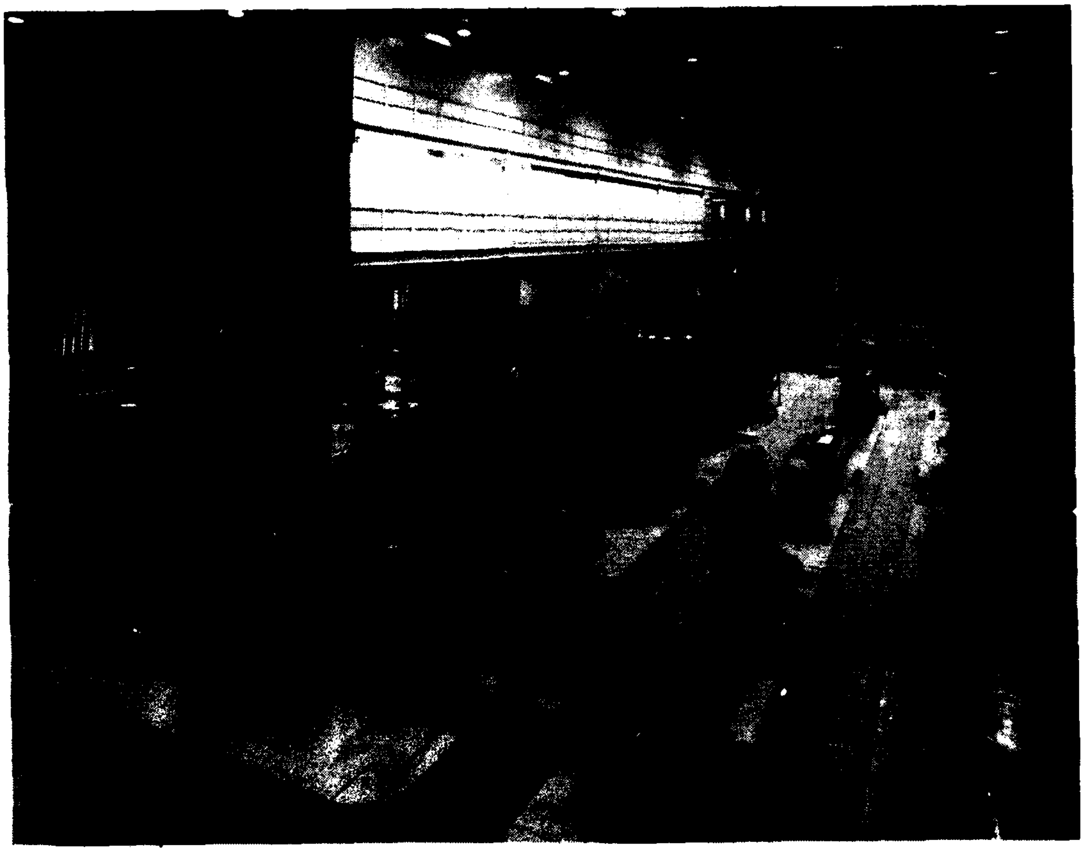

FIGURE 3-4: THE ADVANCED MACHINING SYSTEM IS BEING IMPLEMENTED AT GENERAL DYNAMICS

This program is described as the core effort in establishing a factory of the future at GDFW.

A copy of the AMS brochure can be obtained from:

U.S. Air Force
Wright Aeronautical Laboratory
Attn: AFWAL/MLTM
Wright-Patterson AFB, OH 45433-6533
(513) 255-5151

-- OR --

Mr. Robert L. McMahon Jr.
General Dynamics
Fort Worth Division
Forth Worth, Texas 76101
(817) 777-5073

FLEXIBLE MACHINING SYSTEM (FMS)

The FMS is the visible, working part of the AMS. It is able to machine, inspect, and deburr a wide range of complex, contoured aircraft parts without human intervention. The FMS has six 5-axis CNC machining centers. Tilting rotary tables tilt 121 degrees and rotate 360 degrees to provide a wide range of machining capability. The machining centers have automated tool monitoring and tool changing. Tool identity is verified by reading a programmable microchip embedded in each tool holder.

Material handling is accomplished by an automated guided vehicle (AGV). The AGV carries cutting tools from the crib to the machines. It also delivers part pallets to and from the load/unload area, machine tools, and coordinate measuring machines (CMM's). Part dimensions are checked on two CMM's, which are equipped with both touch and laser probes. The CMM's automatically change probes as required. Raw materials are stored in an AS/RS and delivered to the load/unload area where they are loaded and clamped onto pallet fixtures by robots utilizing vision for location. Parts are washed on each machining center before leaving by flooding with a 135 gallon per minute coolant stream which washes chips and debris into a central coolant reclamation system.

The FMS is controlled and managed by several independent computer processors linked by a high speed local area network. The system is linked to the factory Integrated Manufacturing System to link engineering and management functions and to access Shop Floor Control System data. Artificial intelligence is used to schedule all FMS activities. The FMS is currently in place and being integrated. Four of the six machine tools are producing F-16 machined parts. The integration effort is scheduled for completion in early 1989.

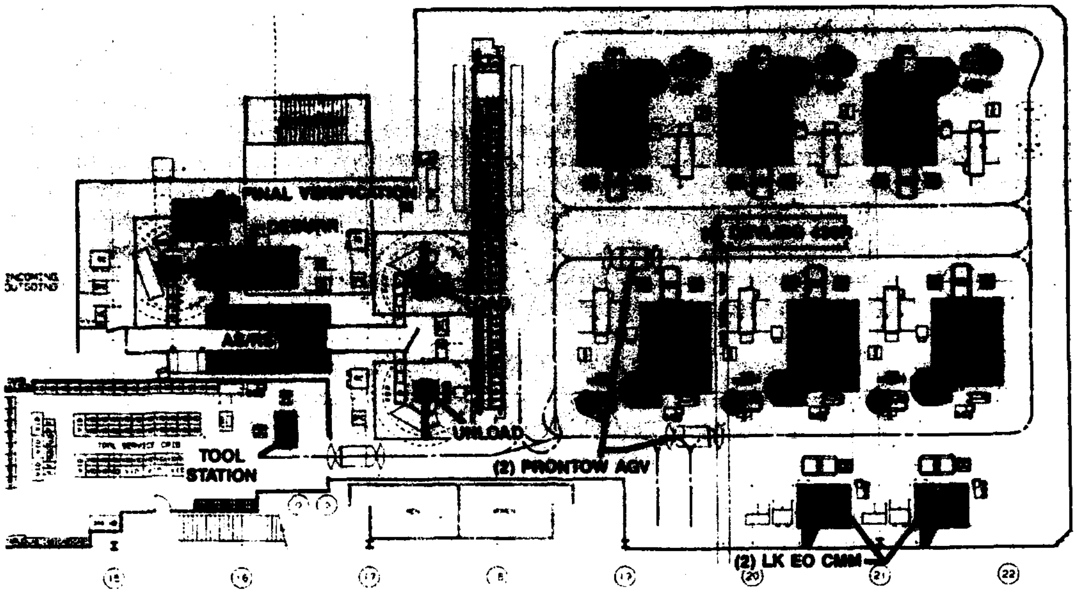

FIGURE 3-5: FMS ARRANGEMENT ON THE FACTORY FLOOR

AUTOMATED NUMERICAL CONTROL (ANC)

The ANC project is a part of the AMS program and is intended to automate the generation of numerical control data for machined parts. The system automatically performs functions normally accomplished by NC engineers or parts programmers. The functions include activities such as product design analysis, NC tactics planning, machine tool path programming, and data management.

The initial use of the system was for sheet metal flat panel parts and the generation of APT nest programs for sheet metal production. The project has moved into a more advanced development phase using CADAM based data sets with feature based design technology to develop parts programs, cutter lists, graphics aids, billet preparation data, cutting tool selection, operator instructions, etc. ANC is in a pilot production status with usage continuously increasing.

This effort involved the development of support systems to execute, store, and exchange data. These developments have provided the tools for the integration of the ANC with other elements of GDFW's "Factory of the Future," including engineering, planning, and shop floor control systems.

FIXTURE FABRICATION - STANDARD CLAMPING DEVICES

A simple standardized method for the design, fabrication, and operation of fixturing for prepared billets, which are to be machined and inspected within the FMS, was developed within the ANC project. Information from the ANC programs is used not only to machine the part, but also to machine holding fixtures to indicate placement of standard clamping devices (ring clamps and 1/2 inch x 13 bolt assemblies). Robotic loading and unloading of the fixtures are accomplished on standard tilting rotary table tooling posts.

ROBOTIC SYSTEMS

GDFW has focused its use of robotics on less expensive commercially available systems. These systems have primarily been applied to fastener hole applications and have retained some traditional drilling aids, such as the use of templates, to obtain the required tolerances for interchangeable and replaceable parts. GDFW has been innovative in its use of robotics through multiple workstations and multiple part fixturing. End effectors, drill/countersink tools, and routing tools are located at each workstation for maximum robot efficiency, along with redundant tools to account for tool wear, which is monitored through sensor feedback.

Robotic aids in use by GDFW include one-stroke drill/countersink tools, compliant end-of-arm tooling, multi-axis positioning system, generic programs to service a variety of parts, and safety systems such as infrared safety beams and pressure pads.

GDFW robotic applications:

* Drill and countersink aluminum and graphite skins into aluminum substructures.
* Rivet and sealant installation.
* Rout aluminum skins.
* Aluminum and steel tube deburring using tactile feedback.
* Steel and aluminum canopy frame preparation.
* Brush deburring of aluminum parts.
* Connector filler insertion.
* Drill and rout bonded panel assemblies.
* Material handling of raw aluminum billets and machined parts.

ROBOTIC TUBE FLARING AND FLARE NUT ASSEMBLY

A robotic work cell for small tubing flare nut assembly and tube end flaring is currently in final development stages in the GDFW robotics lab. The system uses an IBM 7510 six-axis hydraulic robot with GDFW designed flare nut assembly feeders and tube presentation devices. Tubing sizes include 1/4, 5/16, and 3/8 inch diameters in lengths up to 48 inches.

The robot picks up a tube and passes it through the flare nut assembly feeders to place the assemblies on the tube in their proper orientation. The robot then presents each end of the tube into a tube flaring machine to complete the assembly.

SHOP FLOOR CONTROL SYSTEM

GDFW's approach to shop floor control offers several advantages over other systems. Resource requirement planning, job scheduling, and work instructions with visual aids are combined into an effective means of controlling the flow of work through the plant. Dynamic job selection offers significant advantages over non-automated systems.

One of the main thrusts is to remove paper from the shop environment and replace it with IBM 3295 touch screen systems. Currently 110 terminals are in place with approximately 3000 projected installations by 1994. GDFW plans to have units at all workstations. These units are keyboardless, durable, user friendly, and have been well accepted by personnel on the shop floor. Shop people seem to be interested and want to see these systems successfully implemented to track and display all shop order information.

The IBM 3295 is compatible with all of GDFW CIM efforts.

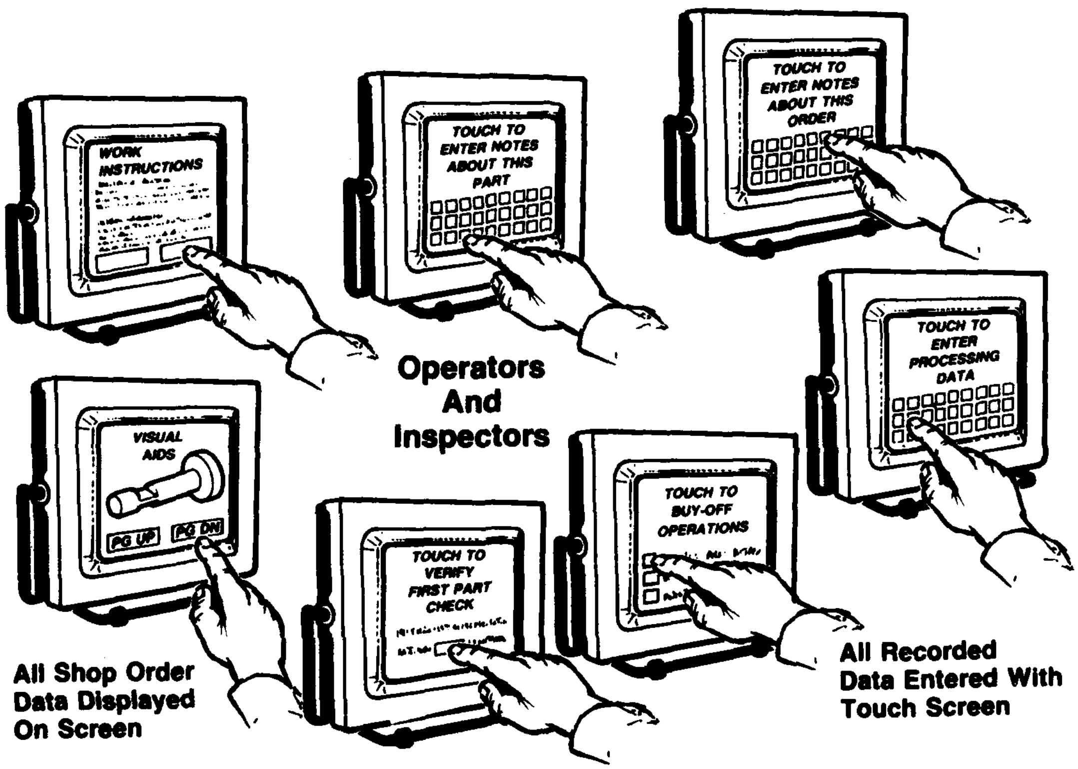

FIGURE 3-6: TOUCH SCREENS ARE USED FOR SHOP FLOOR CONTROL SYSTEM DATA ENTRY

SHEET METAL FABRICATION SYSTEM

The Sheet Metal Fabrication System receives aluminum sheets and automatically produces and delivers routed and drilled flat sheet metal parts for manual unloading into a sheet deburr machine. The system handles 4 foot by 12 foot aluminum sheets by .020 to .250 inch thick. A nesting program selects and lays out a set of parts to achieve full sheet utilization and to meet production requirements. Part quality is improved over blank and pierce operations. The system is highly flexible and can produce new parts within hours after the part design is completed. The system consists of six modules:

Automated Storage and Retrieval System (AS/RS)

The system receives 4 foot by 12 foot aluminum sheets stacked up to 10 inches high on wooden shipping skids from a side loading fork truck. There are 60 storage bins. The system maintains a computer record of material inventory and location. The manufacturer is Webb Triax, Cleveland, OH.

Sheet Loader

The loader is vacuum operated and removes sheets one at a time and stacks them to a maximum of .50 inch high on plywood covered tracked carriers. The manufacturer is Airlock, Birmingham, AL. The sheets are automatically checked for hardness and grain direction during this stacking operation.

Material Handling System (MHS)

This is a smooth precision car-on-track system which transports the stacked sheets from the loader through the process to the manual unload station. It positions the carriers to +/-.020 inch at the router/drill station. The manufacturer is SI Handling Systems, Easton, PA.

Router/Drill

This module contains a single spindle router, 12 drilling spindles, and a lag screw insertion/removal mechanism. The stack of sheets is attached to the plywood by lag screws for retention and positional accuracy. The router/drill is a modified Series 110 gantry router manufactured by Ekstrom, Carlson and Company, Rockford, IL.

Unload and Finish Station

Parts are unloaded manually and fed into a 50 inch wide single pass machine which deburrs both sides. It is manufactured by Abrasive Engineering and Manufacturing, Olathe, KS.

Controls

The cell controller is a VAX II computer. It serves as host, providing operational data and monitoring the system's status through links to the AS/RS computer (Intel 8086), the router/drill controller (Allen Bradley 8200) and the material handling controller (Allen Bradley PLC 4). The system has been utilized in production since mid-1986. The control system is currently linked to the factory mainframe computer to access CAD part design data, material data, and production control data. GDFW plans to fully integrate the system with other factory systems as they are implemented at a later date.

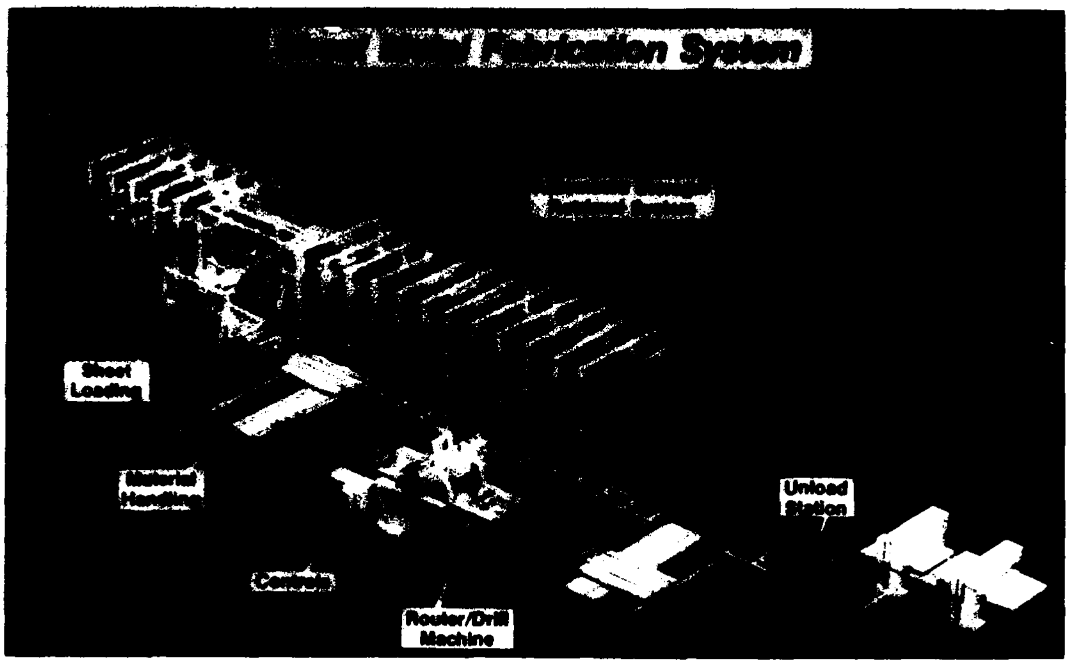

FIGURE 3-7: THE SHEET METAL FABRICATION SYSTEM PRODUCES FLAT BLANKS FROM SHEET STOCK

COMPOSITE PART MANUFACTURING

GDFW manufactures graphite/epoxy parts for the F-16 empennage, including leading edges, horizontal stabilizer skins, vertical skins, and substructure. Part build-up is primarily accomplished by Ingersoll tape laying machines (TLM) although manual lay-up methods are also used. Parts are laminated on flat tools. A digital shear is used to cut the tape to proper lengths and at any angle, with a segmented slitter used to separate graphite fibers. Completed laminates are trimmed to near net shape using a "pizza cutter" located on the tape laying head.

The composite shop employs an automated guided vehicle (AGV), which follows a fluorescent paint trail on the shop floor rather than a guide wire embedded in the floor. This allows for a high degree of flexibility at minimal cost.

Reusable bags are utilized when curing parts in modified bonding and curing presses. Temperature, pressure, and vacuum are automatically monitored and controlled through an Automated Cure Control System (ACCS), which enables one operator to monitor 14 presses.

Cured parts are currently trimmed to net shape through manual abrasive water jet cutting techniques. GDFW has developed a tape temperature control system for the lay-down of low tack prepregs such as bismaleimide (BMI) tape. The system uses hot air blown into a distribution block, which heats and enhances the tack of the BMI tape just prior to lay-down. The entire system, including the TLM, is controlled by the Acramatix T75C CNC control system.

ROBOTIC DRILLING/COUNTERSINKING OF CANOPY ASSEMBLIES

GDFW has developed an automated robotic drilling and countersinking cell for the F-16 canopy structure assemblies and subassemblies. The cell utilizes a Cincinnati Milacron T3/776 robot mounted on a track system to service three separate workstations. The first station uses a four-sided cube positioner for loading up to eight different subassemblies for drilling and countersinking. The other two stations each use a tilting part positioner to present one-seat and two-seat canopy assemblies to the robot for drilling.

Using drill templates, the drilling cell maintains a tolerance of +/-.003 inch which is required for interchangeable and replaceable parts. One-stroke drill/countersink tools are used, along with built-in sensors on the end effectors to detect dull cutters. Multiple end effectors are located at each station to help minimize robot travel time.

One person manages the cell during the day shift. The same person loads the three stations and schedules the executive controller at the end of the shift to run up to an 18 hour unmanned operation utilizing all four sides of the Station 1 cube position, a single place canopy assembly in Station 2, and a two seat canopy assembly in Station 3. Movement of the cube positioner and the robot to Stations 2 and 3 is all automatic through the cell controller.

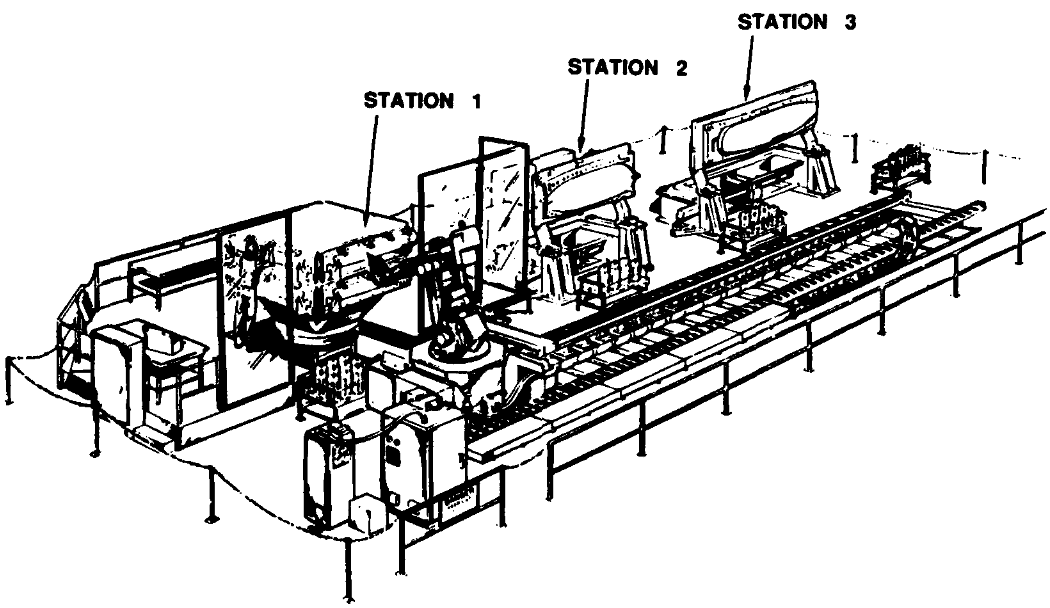

FIGURE 3-8: THE F-16 CANOPY DRILL/COUNTERSINK ROBOT MOVES BETWEEN WORKSTATIONS

TECHNOLOGY TRANSFER

The F-16 Industrial Modernization Incentives Programs at GDFW have resulted in the availability of valuable technology. Much of the technology has been used in the AMS program and is now available to interested parties via the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, VA, 22304-6145, attention DTIC-FDAC. Appendix B provides a listing of available reports by project name.

3.5 MANAGEMENT

INTRODUCTION

A broad range of topics was reviewed in the areas of risk management, configuration control, failure reporting and corrective action, subcontractor control, and people initiatives. A strong commitment to quality going beyond mere compliance with contract specifications was very evident. Pride and a genuine desire to do the job right were apparent at all levels. The management approach stresses teamwork within the division, with the customer, and with suppliers.

The company has undertaken a number of initiatives to bring about major cultural changes and has effectively managed them with strong emphasis from top management and participation by all personnel. These initiatives are improving quality and productivity and are reducing costs. The cornerstone of these initiatives is a formal Productivity/Quality Improvement Program (P/QIP) which provides personnel motivation and a means to monitor over ninety feedback parameters across all major organizations, both blue and white collar.

QUALITY ASSURANCE INITIATIVES

The Fort Worth Division quality assurance program reflects General Dynamics' corporate policy. In addition to using a number of common corporate procedures, the Division has developed its own or additional procedures that extend from its customers, through its own operations, and down to its suppliers. Examples of these procedures include co-locating QA personnel with many organizations, such as design, plant operations, final testing, field operations, and subcontractors. The Division participates with other prime contractors in helping suppliers improve quality. GDFW runs training programs for supervisors and over 300 work specialties. A QA supervisor accompanies the first F-16 delivery to each new customer, base, or using organization. The Division is implementing a broad quality engineering strategy, which includes its own "Excellence for Use" templates.

EMPLOYEE INVOLVEMENT PROGRAMS

Policies and procedures for attracting and retaining qualified people are well designed and appear to be highly effective. Emphasis is placed on starting with qualified people, assigning them well, then continuing with personal and career development. An effective performance management system is used to plan, review, and appraise performance. Supervisory quality is enhanced by training, appraisal, and employee development workshops.

GDFW has a number of inter-related employee involvement programs for developing and implementing effective systems and processes to help management and employees improve communication, productivity, and quality. These programs include: Quality Circles, Employee Involvement Task Teams, Job Enhancement Teams, and a formal Engineering Quality Improvement Process. The functions of these groups and processes are to:

Diagnose organizational needs and problems
Prescribe solutions
Implement solutions
Train participants in the skills required to accomplish the above functions.

Key factors which contribute to the success of employee involvement programs are training of team leaders and members along with management support at all levels.

Quality circles and other employee involvement programs are considered important because of their role in improving productivity and quality and in changing corporate culture.

SURVEY OF EMPLOYEES

GDFW has implemented a corporate-wide employee survey process designed to improve organization performance. The survey provides ongoing assessment of employee attitudes toward company policies and procedures, management practices, and job satisfaction. The results are used to respond to employee needs, customer expectations, and the changing business environment. The first survey was conducted in September 1986. It was followed by a two year process during which all employees are given the opportunity to participate in:

* Feedback meetings to clarify survey results;
* Action planning meetings to recommend and plan improvements;
* Implementation of improvements;
* Follow-up meetings to status action items and discuss new issues.

The entire survey process will be repeated approximately every two years. Top corporate management places strong emphasis on the survey process and constant improvements are expected. GDFW believes that the most reliable source of information about the organization is the employee, thus the survey process has become a key tool for achieving major cultural change throughout the corporation.

ETHICS PROGRAM

GDFW has developed and issued written corporate standards of business ethics and conduct. All GDFW employees have been given a copy and have signed a statement that they have read it. Formal implementation, including a program of training, communications, investigations, and sanctions has been accomplished. A key feature of the program is a hotline that employees can use to request advice or to report concerns. The hotline is used extensively, with about 2/3 of the callers asking for advice on how to avoid situations that would be inconsistent with the standards.

The policy is a key corporate initiative affecting the entire company culture. It has been well implemented and is given strong emphasis from top management.

3.6 TRANSITION PLAN

ANALYSIS RELEVANT TO WILLOUGHBY TEMPLATES

GDFW has made a commitment to evaluate, understand, and incorporate many of the new DOD and USAF initiatives on design and manufacturing. The objectives of this commitment are:

* Attain early system maturity with high readiness rate and combat availability.
* Reduce acquisition and O&M costs.
* Provide affordable capability growth in production and fleet upgrades.

The Willoughby Templates are utilized and tailored or modified as necessary to adapt to program, customer, and program phase requirements. An assessment of compliance with government initiatives such as DOD 4245.7-M, USAF R&M 2000, and others is being accomplished. The F-16 and other programs are being reviewed with the intention of using the Willoughby Templates and other government and company initiatives in a mutually supportive approach.

RELIABILITY & MAINTAINABILITY (R&M) PROGRAM

The F-16 program gives early emphasis to R&M by fully staffing and funding a disciplined program up-front. An R&M Element Manager reports directly to the Program Director, thus assuring appropriate management attention to R&M. Trade-off studies are done early - prior to full scale development (FSD). A firm R&M baseline is established at the start of FSD. Reliability and maintainability testing are accomplished early in development and production. A very effective field feedback system is utilized. Changes and improvements based on field feedback data improved F-16 reliability from 1.7 mean flight time between failures (MFTBF) to over 3.0 in the first 2-1/2 years of production.

The R&M program is based on MIL-STD-785 and MIL-STD-470, respectively. Efforts are underway to incorporate current DOD and Air Force design, test, and manufacturing initiatives in future contracts. These initiatives include the DOD 4245.7M Templates, DOD Concurrent Design Program, Variability Reduction Program, and USAF R&M 2000.

APPENDIX A

TABLE OF ACRONYMS

Acronym	Definition
ACCS	Automated Cure Control System
ADAMSYS	Advanced Damage Analysis Modular System
AFB	Air Force Base
AFPRO	Air Force Plant Representative Office
AGV	Automated Guided Vehicle
AIA	Aerospace Industries Association
AMRF	Automated Manufacturing Research Facility
AMS	Advanced Machining System
ANC	Automated Numerical Control
APT	Automatic Programming Tool
AS/RS	Automated Storage and Retrieval System
ASIP	Aircraft Structural Integrity Program
ATSARS	Automated Tool Storage and Retrieval System
AUTOCRK	Automatic Crack Prediction Program
BMI	Bismaleimide
BMP	Best Manufacturing Practices
CAD/CAM	Computer Aided Design/Computer Aided Manufacturing
CADAM	Computer-Graphics Augumented Design and Manufacturing
CATIA	Computer Aided Three-Dimensional Interface Applications
CDS	Central Data System
CIM	Computer Integrated Manufacturing
CMM	Coordinate Measuring Machines
CMOLS	Contour Measurement of Large Shapes
CNC	Computer Numeric Control
COMOK	Computer Mock-up
CFD	Computation Fluid Dynamics
DNC	Distributed Numeric Control
DOD	Department of Defense
DTIC	Defense Technical Information Center
ECP	Engineering Change Proposal
ECS	Environmental Control System
EMPF	Electronics Manufacturing Productivity Facility
FLAIR	Factory Liaison and Inspection Resources
FMS	Flexible Manufacturing System
FSD	Full Scale Development

Acronym	Definition
GDFW	General Dynamics, Fort Worth Division
GFE	Government-furnished Equipment
ICMMA	Inventory Control and Material Management in Assembly
IMDBS	Integrated Management Database System
MFTBF	Mean Flight Time Between Failures
MHS	Material Handling System
MIL-STD	Military Standard
MTI	Metalworking Technology, Inc.
NC	Numerically Controlled
O&M	Operations and Maintenance
PDD	Product Definition Data
PDDI	Product Definition Data Interface
PDES	Product Definition Exchange Specification
PLC	Programmable Logic Controller
P/QIP	Productivity/Quality Improvement Program
PRAM	Productivity, Reliability, Availability, Maintainability
QA	Quality Assurance
R&M	Reliability and Maintainability
SFCS	Shop Floor Control System
TLM	Tape Laying Machine
USAF	United States Air Force

APPENDIX B

AVAILABLE F-16 IMIP REPORTS

For copies of final reports, write to the Defense Technical Information Center, Cameron Station, Virginia 22314, Attention: DTIC-DDR and request the report by the report number listed below. An L at the end of the DTIC designation indicates a document that is unclassified but limited in distribution. A request must be filed on a DTIC Form 55 with the contract number and justification. Delivery will take approximately six weeks.

Final reports also may be obtained from the Defense Logistics Studies Information Exchange (DLSIE/LD), U.S. Army Logistics Management Center, Fort Lee, Virginia 23801.

G.D. DOC. NO.	DATE	PROJECT	NAME	CONTRACT NO.	REPORT NUMBER DTIC/AD	DLSIE/LD
TM 27	07/80	5.4.15	Automatic Nesting System	F33657-80-G-0007	B059447	49775-C
TM 37	02/81	4.1.5	Cost Tracking and Analysis System	F33657-80-G-0007	B074560	55075-B
TM 38	03/81	4.1.2	Modification Kit Status System	F33657-80-G-0007	B059445	49775-A
TM 39	03/81	5.3.7	Tube Intersecting Cutter for Welded Assemblies	F33657-80-F-0007	B059446	49775-B
TM 40	05/81	4.1.7	Shop Priority Based on Inventory Position	F33657-80-G-0007	B074609	55075-C
TM 41	04/81	5.3.4	Semiautomatic Tube Identification System	F33657-80-G-0007	B074611	55075-A
TM 42	04/81	5.2.5	Hole Inspection Reduction Implementation	F33657-80-G-0007	B074582	55075-D
TM 43	05/81	3.4.1	Semiautomatic Shield Breakout	F33657-80-G-0007	B074608	55075-E
TM 46	08/81	5.4.16	On-Line Alternate Parts Substitution System	F33657-80-G-0007	B074572	55075-F
TM 50		3.1	Common Work Center Requirements	F33657-80-G-0007		
Vol I	06/82		Machining Work Center	"	B074628	55075-XA
Vol II	06/82		Sheet Metal Work Center	"	B074615	55075-XB
Vol III	06/82		Electric Bench Work Center	"	B074580	55075-XC
TM 54	01/82	3.4.8	Materials Handling	F33657-80-G-0007	B074559	55075-R
TM 55	01/82	5.1.5	Fabrication of Skin-to-Core Assemblies	F33657-80-G-0007	B074603	55075-G
TM 59	02/82	5.4.8	Semiautomatic Kitting	F33657-80-G-0007	B074607	55075-S
TM 60	01/82	4.1.6	Machine Tool Maintenance System	F33657-80-G-0007	B074669	55075-T
TM 63	04/82	3.4.2	Semiautomatic Wafer Connector Termination System	F33657-80-G-0007	B074596	55075-U
TM 64	04/82	4.1.1	Integrated MIS Plan	F33657-80-G-0007	B074579	55075-W
TM 66	06/82	3.2.3	Automatic Clamping for NC Machine Tools	F33657-80-G-0007	B074594	55075-V
TM 73	06/82	5.4.10	Automated Marking System	F33657-80-G-0007		55075-K
TM 74	06/82	5.1.1	Automated Broadgoods Lay-Up	F33657-80-G-0007	B074581	55075-P
TM 83	09/82	5.2.1	Automated Wing Drilling	F33657-80-G-0007	B074671	55075-Q
TM 84	09/82	1.0	Factory Integration	F33657-80-G-0007	B074612	55075-L
TM 93	11/82	3.4.4	Electronic Assembly Aid	F33657-80-G-0007	B074595	55075-J
TM 95		4.2.4	Computerized Calibration System	F33657-80-G-0007		
Vol I	12/82		Items 1, 2, and 3	"	B074764	55075-YA
Vol II	12/82		Items 4, 5, and 6	"	B074765	55075-YB
Vol III	12/82		Items 7, 8, and 9	"	B074766	55075-YC
TM 96	01/83	4.2.1	Integrated Quality Assurance Plan	F33657-80-G-0007	B074621	55075-H
TM 98	02/83	3.2.2	CNC Grinding Machine for Carbide Drills	F33657-80-G-0007	B077517	56139-A
TM 99	01/83	3.3.3	Automated Trim Cell	F33657-80-G-0007	B074561	55075-N
TM 101	03/83	4.1.4	Integration of Standardized Planning and Work Measurement	F33657-80-G-0007	B077520	56182-A
TM 102	03/83	3.3.1	Automated Press Brake	F33657-80-G-0007		56183-A
TM 103	03/83	5.1.6	Process Control of Adhesives and Sealants	F33657-80-G-0007	B077434	56180-A
TM 110	05/83	2.0	Cost-Benefit Analysis	F33657-80-G-0007	B077519	56184-A
TM 113	12/83		Phase III - Detailed Work Center Design and Enabling Technologies	F33657-80-G-0007	B080269L	57538-A
TM 114	08/83	3.2.1	Redesign/Rework of Tooling	F33657-80-G-0007	B080299L	57538-B
TM 115	08/83	8.3.11	Electrical Harness Data System (Report - Part I/ Initial Completions 1/1/83 thru 8/30/83)	F33657-82-C-2034	B077514	56181-A
TM 122	09/83	8.2	Receiving/Receiving Inspection Data Processing (R/RIDP)	F33657-80-G-0007	B080249L	57538-C
TM 124	02/84	8.1	Gaugeless Assembly Tool Realignment	F33657-80-G-0007		58528-A
TM 125	01/84	8.3.11	Electrical Harness Data System Initial Project Completions (Report - Part II-2nd Phase Completions - 9/1/83 thru 1/31/84)	F33657-82-C-2034	B080223L	57538-D
TM 126	03/84	8.3.1	Production Productivity/Quality Improvement Study	F33657-82-C-2034	B082512L	58526-A
TM 128	05/84	8.3.5	Robotic Drilling of Canopy Substructure	F33657-82-C-2034	B087936L	57538-E
TM 129	09/84	8.3.11	Electrical Harness Data System	F33657-82-C-2034	B088852L	57538-F
TM 130	01/85	8.3.10	Comprehensive Manufacturing Cost-Tracking System	F33657-82-C-2034	B096077L	64180-H
TM 135	02/85	8.3.8	Automated Painting System	F33657-82-C-2034	B096069L	64180-J
TM 136	02/85	8.3.9	Advanced Laminating Center Improvements	F33657-82-C-2034	B095858L	64180-E
TM 147	05/85	8.3.4	Advanced Wire Harness Manufacturing	F33657-82-C-2034	B096492L	64180-C
TM 148	06/85	8.4.6	Computer-Aided Visual Aids	F33657-82-C-2034	B096379L	64180-A
TM 149	08/85	8.3.2	Automated Cure Control System	F33657-82-C-2034	B098596L	65477-A
TM 150	09/85	8.3.7	Automated Tube Cutting/Welding	F33657-82-C-2034	B098597L	65478-A
TM 152	09/85	8.4.9	Cutting Tool Maintenance Improvement	F33657-82-C-2034	B098636L	64180-DA
TM 153	02/86	8.4.1	EFC Printed Circuit Board Assembly Work Cell	F33657-82-C-2034		64180-FA
TM 156	12/85	8.3.6	Advanced Robotic Control System (ARCS)	F33657-82-C-2034		
TM 163	03/86	8.4.7	Automated Tube Processing	F33657-82-C-2034		
TM 173	07/86	8.4.8	Comprehensive Cost-Tracking System – Phase II	F33657-82-C-2034		
TM 174	07/86	8.3.3	Sheet Metal Fabrication System	F33657-82-C-2034		

APPENDIX C

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